STATISTIČKA ANALIZA REZULTATA ISPITIVANJA KVALITETA BETONA

STATISTICAL ANALYSIS OF CONCRETE QUALITY TESTING RESULTS

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1 UVOD

Ocena kvaliteta betona ugrađenog u neku betonsku, odnosno armirano-betonsku konstrukciju, zahteva kontinualno ispitivanje osnovnih fizičko-mehaničkih karakteristika kontrolnih betonskih uzoraka, uzetih na mestu proizvodnje (u fabrici betona) i na mestu ugradnje (na gradilištu). Cilj ovog istraživanja jeste da se izvrši kritička ocena kvaliteta betona koji se proizvodi i ugrađuje na tržištu Republike Srbije, uzimajući u obzir osnovne parametre kvaliteta - čvrstoću pri pritisku (marku betona) i izmerenu zapreminsku masu u očvrslom stanju. Ispitivanja o kojima je reč obavljena su na ukupno 4.420 kontrolnih betonskih uzoraka, oblika kocke ivice 15 ili 20 cm. Predmetne kocke uzorkovane su na petnaest betonskih baza, odnosno na 50 gradilišta različitih armirano-betonskih konstrukcija koje je izvodilo dvadeset dva izvođača, u periodu od januara do decembra 2012. godine. Od ukupnog broja ispitanih uzoraka, 75% dostavljeno je s gradilišta koja se nalaze na široj teritoriji grada Beograda, a 25% iz drugih delova Srbije (Vojvodina, Zlatiborski okrug, Pirotski okrug, Raška oblast i Podrinje). Imajući u vidu da se najveći deo građevinskih radova u našoj zemlji izvodi baš na široj teritoriji grada Beograda, možemo smatrati da ispitivani uzorci daju prilično reprezentativnu sliku o kvalitetu betona koji se proizvodi i ugrađuje u Republici Srbiji.

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1 INTRODUCTION

Quality assessment of concrete placed in an ordinary concrete or reinforced concrete structure, requires continuous testing of basic physical-mechanical properties on control specimens taken either at the production site (i.e. concrete plant) or at the placement site (i.e. construction site). The main objective of this research is to perform a critical quality assessment of concrete which is produced and built in at the Serbian market, considering the basic quality parameters – such as compressive strength (i.e. class of concrete) and density measured in the hardened state. This investigation was carried out by testing a total number of 4420 control concrete specimens in the shape of cubes with 15 or 20 cm sides. Sampling of these cubic specimens was performed at 15 concrete plants, i.e. at 50 different reinforced concrete construction sites managed by 22 contractors, covering a period from January until December 2012. From the total number of tested samples, 75% were delivered from sites in Belgrade city and surrounding area, and the rest of 25% from other Serbian regions (Vojvodina, Zlatibor county, Pirot county, Raška province and Podrinje region). Considering the fact that most of the construction work in our country is performed in the city of Belgrade and its outskirts, we can assume that the tested samples can

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U svim razmatranim slučajevima, beton je na gradilište dopreman automikserima, nakon čega je ugrađivan u kalupe oblika kocke ivice 15 cm ili 20 cm. Uzorkovanje i negu betonskih uzoraka sprovodili su izvođači betonskih radova, u skladu s važećim standardima i to: SRPS EN 12350-1:2009, SRPS EN 12390-2:2009 i SRPS ISO 2736-2:1997. Uzorci su pri starosti od dvadeset osam dana (ili nešto ranije, u kom slučaju je negovanje nastavljano u laboratoriji), isporučivani Laboratoriji za materijale Građevinskog fakulteta u Beogradu, gde su obavljena predmetna ispitivanja. Čvrstoća pri pritisku betonskih uzoraka ispitivana je u skladu sa standardom SRPS ISO 4012:2000, a određivanje zapreminske mase prema odredbama SRPS ISO 6275:1997. Tokom statističke analize podataka, akcenat je stavljen na vrednosti čvrstoće pri pritisku betonskih uzoraka, koje predstavljaju svakako najbitniji parametar za ocenu kvaliteta betona.

2 EKSPERIMENTALNO ISTRAŽIVANJE

U ovom istraživanju, centralno mesto zauzima statistička analiza zasnovana na rezultatima ispitivanja čvrstoće pri pritisku i zapreminske mase kontrolnih betonskih uzoraka (kocki ivice 15 cm ili 20 cm). Iako se dokaz marke betona, po još uvek važećem Pravilniku za beton i armirani beton - PBAB'87 [6], zasniva na karakterističnoj dvadesetosmodnevnoj čvrstoći pri pritisku betonskih uzoraka oblika kocke ivice 20 cm, danas je evidentna dosta češća upotreba uzoraka oblika kocke ivice 15 cm. Ovakav trend, s jedne strane, jeste posledica usklađivanja tehničke regulative u oblasti građevinarstva sa evropskim zemljama - u kojima se (po standardu EN 12390) klasa čvrstoće betona dokazuje na cilindrima Ø15/H30cm ili na kockama ivice 15 cm. S druge strane, ovakav trend takođe je posledica i dugogodišnjih teškoća u pogledu manipulacije s kalupima, negovanjem i ispitivanjem betonskih kocki ivice 20 cm. Iz tih razloga, čak 90% ispitanih uzoraka tokom 2012. godine činile su kocke ivice 15 cm. Kako bi omogućili adekvatnu analizu rezultata ispitivanja, kao i njihovo poređenje s projektovanim markama betona, čvrstoće betona pri pritisku dobijene na uzorcima oblika kocke ivice 15 cm prethodno su preračunate na čvrstoću pri pritisku kocki ivice 20 cm, množenjem sračunatih vrednosti koeficijentom konverzije k=0.95 (u skladu s Pravilnikom BAB'87).

Uzorkovanje betona vršeno je manjim delom u fabrikama betona (20%), a većim delom na gradilištima (80%). U ovu drugu grupu svrstavaju se objekti različite namene: 92.0% uzoraka s poslovno-stambenih objekata, 3.8% s mostovskih konstrukcija i 4.2% sa industrijskih objekata.

3 REZULTATI ISPITIVANJA I DISKUSIJA

Iako se i prema domaćim i prema inostranim standardima marka betona (odnosno klasa čvrstoće) dokazuje na uzorcima starosti dvadeset osam dana, često postoji potreba da se i nešto ranije dođe do određenih pokazatelja kvaliteta ugrađenog betona. Svakako, prvi takav pokazatelj - koji se može dobiti praktično odmah nakon spravljanja i ugrađivanja betona - jeste zapreminska masa betona u svežem stanju. Po

give a fairly representative picture regarding the quality of concrete which is produced and placed in Serbia. In all the cases, concrete was transported by mixer trucks and afterwards placed in 15 or 20 cm cubic moulds. Sampling and curing concrete specimens was done by the contractors, according to the valid standards, such as: SRPS EN 12350-1:2009, SRPS EN 12390-2:2009 and SRPS ISO 2736-2:1997. The samples were delivered at the age of 28 days (or earlier, in which case the curing was continued in the lab) and afterwards tested in the Laboratory for materials at the Faculty of Civil Engineering, University of Belgrade. Compressive strength of concrete was tested according to SRPS ISO 4012:2000, and density according to SRPS ISO 6275:1997. During the statistical analysis, the accent was put on the concrete specimens' compressive strength values, which certainly represent the most important parameter for concrete quality assessment.

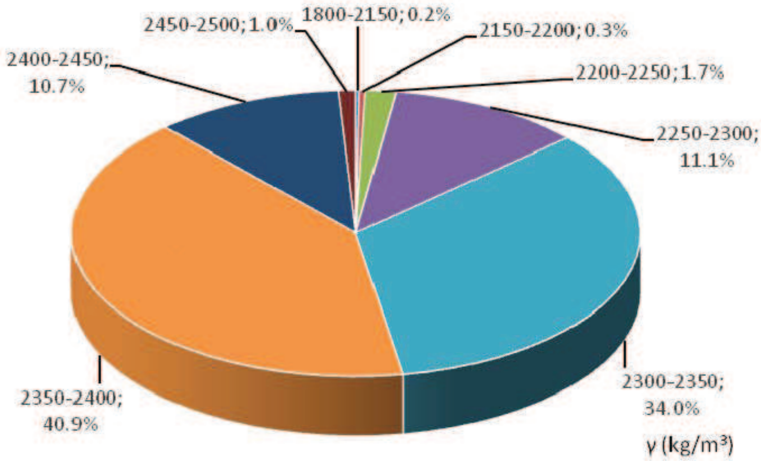
2 EXPERIMENTAL RESEARCH

The central point in this research has the statistical analysis based on compressive strength and density testing results of control concrete samples (cubes with 15 or 20 cm sides). Although the still valid Rulebook for concrete and reinforced concrete (PBAB'87) prescribes using characteristic 28-day compressive strength obtained by testing the 20cm cubic specimens in order to prove the class of concrete, it is evident that today the application of 15cm specimens has become more frequent. Such a trend is a consequence of the technical regulation harmonization process with the European countries in the field of Civil engineering – in which (according to EN 12390) the concrete class should be proved on Ø15/H30cm cylindrical specimens or 15cm cubic specimens. On the other hand, this trend is also caused by the long-lasting difficulties related to mould manipulation, curing and testing of 20cm cubic specimens. Therefore, even 90% of specimens tested during 2012 were 15cm cubes. In order to make possible an adequate analysis of testing results, as well as their comparison with designed concrete classes, concrete compressive strengths obtained using 15cm cubic specimens were recalculated to 20cm cubic specimens, multiplying the experimental values by conversion coefficient k=0.95 (according to the Rulebook BAB'87). Sampling of concrete was performed partially at the concrete plants (20%), but to a greater extent at the construction sites (80%). The latter group consists of structures with different purposes, such as: 92.0% samples coming from commercial/residential buildings, 3.8% from bridge structures and 4.2% from industrial facilities.

3 RESEARCH RESULTS AND DISCUSSION

Although, according to both domestic and international standards, the proof of concrete class has to be established by testing 28-day old specimens, sometimes it is necessary to make an early assessment of in situ concrete quality. Certainly, one of the first parameters that could be obtained right after mixing and placing concrete is its density in the fresh state. By the rule, the increment of concrete's density also implies its pravilu, povećanje zapreminske mase betona podrazumeva i veće čvrstoće pri pritisku i zatezanju, kao i poboljšanu otpornost na dejstvo mraza i otpornost na dejstvo mraza i soli, zatim viši stepen vodonepropustljivosti, itd. Isti trend važi i kada je reč o odnosu između vrednosti zapreminske mase betona u očvrslom stanju i navedenih parametara kvaliteta betona. Na slici 1 prikazani su rezultati ispitivanja zapreminskih masa na 4.420 kontrolnih uzoraka betona u očvrslom stanju.

higher compressive and tensile strength, as well as better freeze/thaw and deicing salts resistance, higher degree of water tightness, etc. The same tendency exists when the relations between concrete's density in hardened state and its other above mentioned quality parameters are concerned. Figure 1 show the experimental results obtained after testing density in hardened state on 4420 control concrete samples.



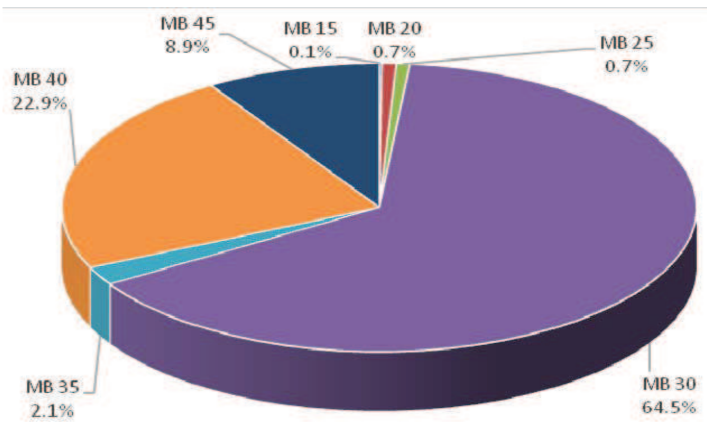
Slika 1 – Zapreminske mase betona u očvrslom stanju
Figure 1 – Densities of hardened concrete

Prikazani rezultati ispitivanja pokazuju da su kod 14.4% uzoraka izmerene zapreminske mase niže od 2.300 kg/m^3. Znatno veći procenat uzoraka - 34.0% - imao je zapreminsku masu između 2.300 i 2.350 kg/m^3, a kod čak 40.9% uzoraka ovo svojstvo variralo je između 2.350 i 2.400 kg/m^3. Kod 10.7% uzoraka izmerene su relativno visoke vrednosti zapreminske mase od preko 2.400 kg/m^3. Imajući u vidu da se uobičajene vrednosti zapreminske mase kod klasičnih betona kreću u granicama od 2.300 do 2.400 kg/m^3, dobijene vrednosti ukazuju na potencijalno dobar kvalitet betona.

Na slici 2 prikazana su procentualna učešća pojedinih projektovanih (zahtevanih) marki betona u ispitivanom statističkom uzorku.

The presented experimental results show that 14.4% of samples had densities lower than 2300 kg/m^3. Much higher percentage of samples (34.0%) had the density values ranging between 2300 and 2350 kg/m^3, and for another 40.9% of samples this property varied between 2350 and 2400 kg/m^3. At 10.7% of samples, relatively high values of density were measured - exceeding 2400 kg/m^3. Considering the fact that the usual values of density of normal concrete range between 2300 and 2400 kg/m^3 the obtained values suggest potentially good concrete quality.

Figure 2 shows the contribution of different designed (required) concrete classes, expressed in percent of the analyzed statistical sample.



Slika 2 – Učešća projektovanih marki betona (%)
Figure 2 – Contribution of designed concrete classes (%)

Imajući u vidu da se za većinu građevinskih objekata upotrebom betona projektovanih marki MB30 i MB40 mogu zadovoljiti uslovi graničnog stanja nosivosti i graničnog stanja upotrebljivosti nosećih elemenata konstrukcije, navedena procentualna učešća imaju očekivane vrednosti. Naime, na osnovu prikazanih rezultata vidi se da su najzastupljenije projektovane marke betona MB 30 i MB 40, sa učešćima od 64.5% i 22.9%, respektivno.

Prosečne vrednosti čvrstoće pri pritisku f_p, standardne devijacije σ, koeficijenta varijacije υ, karakteristične čvrstoće pri pritisku σ_{kar} i ostvarene marke betona prikazane su u tabeli 1, za svaku od projektovanih marki betona koje su bile zastupljene u predmetnom istraživanju (od MB15 do MB45).

Having in mind the fact that for most of the concrete structures the application of designed concrete classes MB30 and MB40 can satisfy the conditions of load-bearing limit state and serviceability limit state of bearing structural elements, the above mentioned percentages have expected values. Namely, according to the presented experimental results, it is obvious that the most frequent designed concrete classes are MB 30 and MB 40, with contributions of 64.5% and 22.9%, respectively.

The average values of compressive strength f_p, standard deviation σ, variation index υ, characteristic compressive strength σ_{kar} and achieved concrete class are given in the Table 1, for each of the designed concrete classes that were analyzed in this research (from MB15 to MB45).

Tabela 1 – Prosečne vrednosti analiziranih statističkih parametara u funkciji marke betona
Table 1 – Average values of analyzed statistical parameters related to the concrete class

Projektovana marka betona Designed concrete class	f_p (MPa)	σ (MPa)	υ (-)	σ_{kar} (MPa)	Ostvarena marka betona Achieved concrete class
MB 15	33.4	16.6	0.498	12.1	MB 10
MB 20	24.9	5.9	0.237	17.4	MB 15
MB 25	30.7	5.5	0.177	23.8	MB 20
MB 30	44.9	7.8	0.175	34.8	MB 30
MB 35	48.2	8.3	0.172	37.6	MB 35
MB 40	51.1	7.3	0.142	41.8	MB 40
MB 45	57.6	7.7	0.134	47.7	MB 45

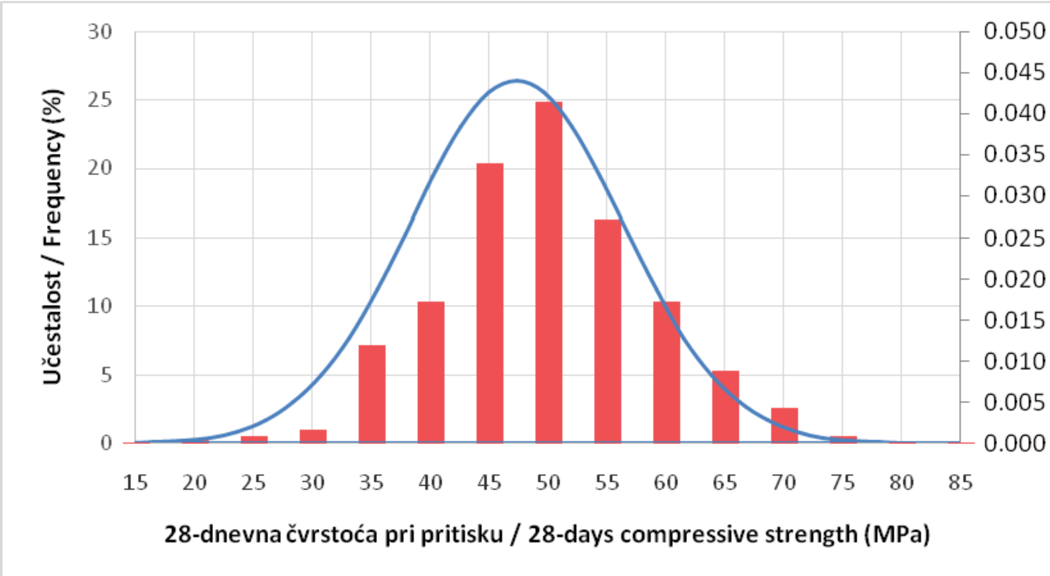
S ciljem dokazivanja marke betona, a s obzirom na broj rezultata ispitivanja, pri proračunu karakteristične čvrstoće pri pritisku (σ_{kar}), korišćena je normalna raspodela slučajne promenljive s fraktilom p=10 % (prema Pravilniku za beton i armirani beton PBAB ’87). Iz tabele 1 jasno se uočava da prosečne vrednosti čvrstoća pri pritisku znatno premašuju projektovane marke betona, dok su razlike u vrednostima karakterističnih čvrstoća pri pritisku i projektovanih marki betona znatno manje. Naime, u slučaju projektovanih marki MB 15, MB 20 i MB 25 nisu zadovoljeni kriterijumi prema Pravilniku BAB ’87, koji se odnose na zahtevanu marku betona. Razlog ovako velikih odstupanja karakteristične vrednosti u odnosu na prosečnu čvrstoću pri pritisku ispitivanih betonskih uzoraka leži u velikom rasipanju rezultata, što dovodi do relativno visokih vrednosti standardne devijacije. Ipak, treba napomenuti da su ovakve vrednosti standardne devijacije delom i posledica statističke obrade podataka koja je vršena na svim uzorcima jedne iste projektovane marke betona, ne uzimajući u obzir druge uticajne činioce (vrstu betona, njegov sastav, proizvođača, uslove transporta, termo-higrometrijske parametre, itd.). Baš zbog očekivanog značajnog rasipanja rezultata, ozbiljniji proizvođači betona pribegavaju proizvodnji betona koji će zadovoljiti neophodne uslove, ne samo za projektovanu marku, već i za jednu marku ili čak dve marke više od projektovane. Osim poboljšanih mehaničkih karakteristika, neka druga svojstva takvih betona (kao što su otpornost na dejstvo mraza, otpornost na dejstvo mraza i soli, vodonepropustljivost itd.) takođe će time svakako biti

Considering the number of testing samples, in order to establish the class of concrete the characteristic value of compressive strength (σ_{kar}) was calculated using normal distribution with 10% fractile (according to BAB ’87). Analyzing the results from the Table 1, it is obvious that the average values of compressive strength (f_p) clearly exceed the designed concrete classes, whereas the differences between characteristic values of compressive strength (σ_{kar}) and designed concrete classes are less pronounced. To be exact, in the case of designed classes MB 15, MB 20 and MB 25 even the minimal required criteria according to the Rulebook BAB ’87 are not satisfied. The reason for such difference between the characteristic values and average values of compressive strength originates from the significant dispersion of testing results and consequently relatively high values of standard deviation (σ). However, it should be mentioned that such values of standard deviation also occur as a result of statistical data processing which was performed on the samples with the same designed concrete class, but without taking into consideration other important influential parameters (such as: type and mix design of concrete, production and transportation conditions, thermo-hygrometric parameters, etc.). Due to expecting significant dispersion of results, respected concrete producers usually tend to make concrete which satisfies not only the required conditions, but also the conditions needed for one or two classes above the designed value. Besides better mechanical characteristics, other properties of such concrete (like freeze-thaw resistance, water tightness, resistance to bolja. Dobijeni rezultati ispitivanja ukazuju na to da su kod deset od ukupno dvadeset dva tretirana proizvođača betona (što čini 45%) zadovoljeni uslovi za prvu ili drugu višu marku betona u odnosu na projektovanu marku u čak 90% slučajeva. Pritom, treba napomenuti da je preko 70% ispitivanih betonskih kocki uzorkovano na gradilištima koja su se snadbevala betonom iz jedne od pomenutih deset fabrika betona.

Na slici 3 prikazana je učestalost rezultata ispitivanja dvadesetosmodnevne čvrstoće pri pritisku na analiziranom statističkom uzorku od 4.420 betonskih kocki.

deicing salts, etc.) will also be improved. The obtained testing results indicate that 10 out of 22 analyzed concrete producers (or 45%) satisfy the conditions for first or second concrete class above the designed value in 90% of cases. At the same time, more than 70% of tested concrete cubes were sampled at the sites supplied by one of the 10 above mentioned concrete plants.

Figure 3 shows the frequency of 28-day compressive strength testing results and probability curve based on statistical sample of 4420 concrete cubes.



Slika 3 – Učestalost ispitivanja i kriva verovatnoće
Figure 3 – Testing results frequency and probability curve

Pritom, prosečna čvrstoća svih ispitanih uzoraka iznosila je 47.0 MPa, standardna devijacija 9.1 MPa, a koeficijent varijacije 0.194. Na osnovu raspodele čvrstoća pri pritisku (prikazanoj na slici 3), može se zaključiti da čvrstoće prate normalnu raspodelu slučajne promenljive koja je definisana izrazom:

In addition, the mean value of compressive strength of all tested specimens amounted to 47.0 MPa, standard deviation 9.1 MPa, and variation index 0.194. Based on the distribution of compressive strengths (see Figure 3), the conclusion can be made that these strengths correspond with the normal distribution of independent variable which is defined as follows:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2 \right) \tag{1}$$

gde je:

σ – standardna devijacija;
μ – srednja vrednost;
x – nezavisno promenljiva.

where:

σ – standard deviation,
μ – mean value,
x – independent variable.

Zavisnost između zapreminske mase u očvrslom stanju i čvrstoće pri pritisku prikazana je na slici 4.

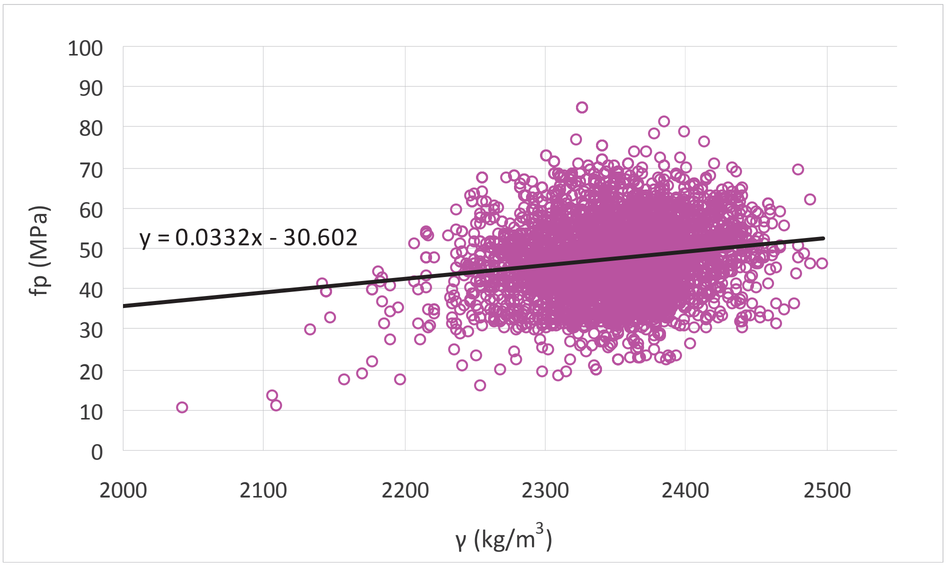
Iako ovakav dijagram ukazuje na veliko rasipanje rezultata, ipak blago nagnuta linearna korelacija pokazuje da se s povećanjem zapreminske mase, u principu, poboljšavaju i mehaničke karakteristike betona.

Imajući u vidu da su svi uzorci ispitivani pri starosti od dvadeset osam dana, na osnovu učestalosti ispitivanja po mesecima, može se sa određenim stepenom preciznosti proceniti i učestalost izvođenja betonskih radova u toku 2012. godine, koja je prikazana

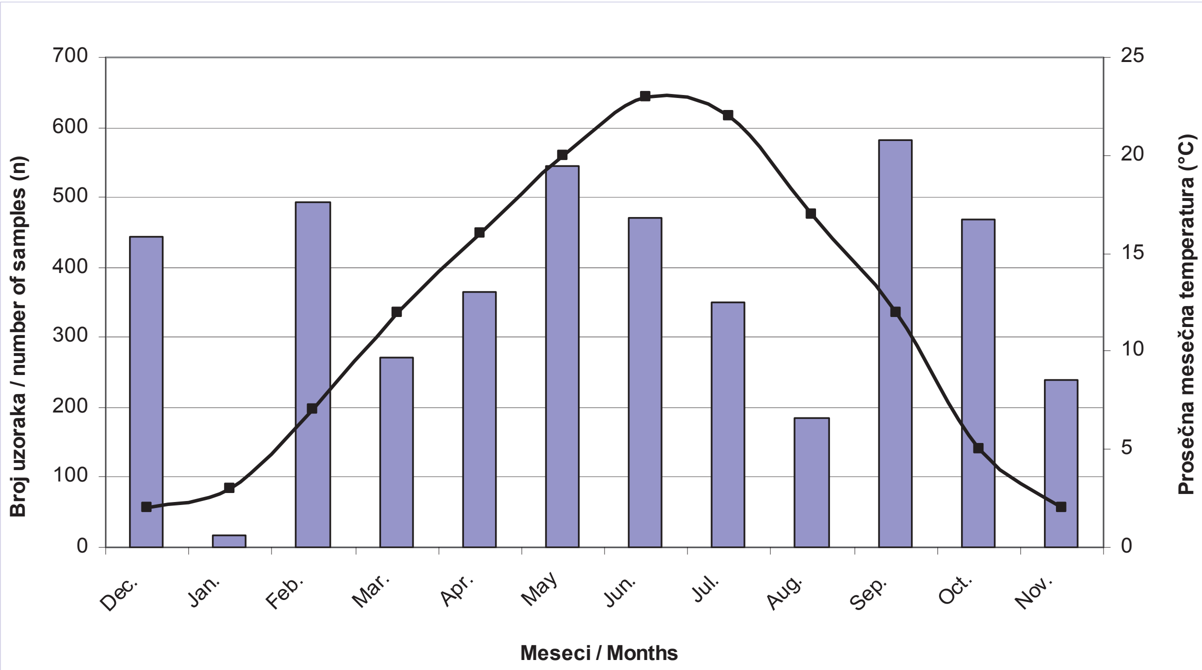
The correlation between the density of hardened concrete and its compressive strength is presented at Figure 4.

Although this diagram shows large dissipation of experimental results, nevertheless the slightly inclined linear correlation suggests that the increase of density generally leads to better mechanical properties of concrete.

Having in mind the fact that all samples were tested at the age of 28 days and taking into account the testing frequency per month, we can make a fairly accurate as-



Slika 4 – Zavisnost zapreminske mase u očvrslom stanju i čvrstoće pri pritisku
Figure 4 – Correlation between the density in hardened state and compressive strength



Slika 5 – Učestalost ispitivanja uzoraka po mesecima i prosečne mesečne temperature vazduha na teritoriji Beograda
Figure 5 – Frequency of testing per month versus average monthly air temperatures in Belgrade area

na slici 5. Na istom dijagramu, prikazane su i prosečne mesečne temperature vazduha na teritoriji grada Beograda [5] u periodu od decembra 2011. do novembra 2012. godine, kada su uzimani uzorci betona koji su ispitivani u Laboratoriji za materijale Građevinskog fakulteta Univerziteta u Beogradu tokom 2012. godine. Na slici 5 jasno se uočava da dinamika izvođenja betonskih radova, u periodu od marta do avgusta 2012. godine, prati promenu prosečne mesečne temperature vazduha. U letnjim mesecima izraženiji je pad aktivnosti na izvođenju betonskih radova zbog povišenih

sumption about the frequency of concrete works execution during 2012 (see Figure 5). At the same diagram, average monthly temperatures in Belgrade area for the period December 2011 – November 2012 are presented [5], which corresponds with the period of sampling and testing of specimens in the Laboratory for materials at the Faculty of Civil Engineering – University of Belgrade. Looking at Figure 5, it is obvious that the dynamics of concrete works execution during the period March-August 2012 corresponds with the change of average monthly temperatures. Throughout the summer maksimalnih dnevnih temperatura koje su za mesece jun, jul i avgust 2012. godine iznosile 35, 40 i 38 °C, respektivno [5]. S druge strane, u zimskim mesecima predmetne godine nisu beležene ekstremno niske temperature, pa su betonski radovi, uz korišćenje specijalnih postupaka (upotreba aditiva za zimsko betoniranje, zagrevanje komponentnih materijala, termička izolacija oplate, grejanje ugrađenog betona, itd.), obavljani nesmetano.

4 ZAKLJUČAK

U radu je prikazana statistička analiza rezultata ispitivanja kvaliteta betonskih uzoraka u Laboratoriji za materijale Građevinskog fakulteta Univerziteta u Beogradu, u toku 2012. godine. Ispitivanja su obavljena na ukupno 4.420 kontrolnih betonskih uzoraka. Rezultati istraživanja o kome je reč pokazuju sledeće:

- 74.9% uzoraka imalo je vrednosti zapreminske mase u očvrslom stanju koje su se kretale između 2.300 i 2.400 kg/m^3, a 10.7% uzoraka zapreminsku masu veću od 2.400 kg/m^3;
- najzastupljenije projektovane, a ujedno i ostvarene marke betona, jesu MB 30 i MB 40, sa ukupnim učešćima od 64.5% i 22.9%, respektivno;
- prosečne vrednosti čvrstoća pri pritisku znatno premašuju projektovane marke betona, dok su razlike u vrednostima karakterističnih čvrstoća pri pritisku i projektovanih marki betona znatno manje, što je posledica značajnog rasipanja rezultata;
- prosečna čvrstoća svih 4.420 ispitanih betonskih uzoraka iznosila je 47.0 MPa, standardna devijacija 9.1 MPa, a koeficijent varijacije 0.194;
- povećanje zapreminske mase uzoraka u očvrslom stanju, u načelu, prati povećanje čvrstoće pri pritisku betona;
- upotrebom odgovarajućih hemijskih dodataka i adekvatnim izvođenjem betonskih radova u posebnim uslovima, a za termohigrometrijske uslove koji važe u Republici Srbiji, može se reći da termin „građevinska sezona” postepeno gubi smisao, jer se betonski radovi – kao što je pokazano - mogu izvoditi praktično tokom cele godine, gotovo nesmetano.

ZAHVALNOST

U radu je prikazan deo istraživanja koje je pomoglo Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije, u okviru tehnoloških projekata TR 36048 pod nazivom „Ispitivanje stanja i metoda unapređenja građevinskih konstrukcija sa aspekta upotrebljivosti, nosivosti, ekonomičnosti i održavanja” i TR 36017 pod nazivom „Istraživanje mogućnosti primene otpadnih i recikliranih materijala u betonskim kompozitima, sa ocenom uticaja na životnu sredinu, u cilju promocije održivog građevinarstva u Srbiji”.

months the reduction of concreting activities is more evident, due to higher daily temperatures, which maximum values in June, July and August of 2012 amounted to 35, 40 and 38 °C, respectively. On the other hand, during the winter months of the same year extremely low temperatures were not recorded, so the concrete works supplemented by special procedures (such as: application of winter concreting admixtures, preheating constituent materials, thermal insulation of formwork, heating the placed-in concrete, etc.) could be continued without problems.

4 CONCLUSION

Statistical analysis of the results obtained after testing compressive strength and density of concrete samples in the Laboratory for materials at the Faculty of Civil Engineering – University of Belgrade during 2012, are presented in this paper. The research included a total number of 4420 control concrete samples. The following conclusions can be derived from the obtained results:

- 74.9% of samples had values of density in the hardened state varying between 2300-2400 kg/m^3 and 10.7% of samples had density higher than 2400 kg/m^3;
- the most frequent designed classes of concrete, as well as the achieved classes of concrete, were MB 30 and MB 40 – with total contributions of 64.5% and 22.9%, respectively;
- the average values of compressive strength significantly exceed the designed concrete classes, whereas the differences between characteristic values of compressive strength and designed concrete classes are less pronounced, which is a consequence of a considerable dispersion of testing results;
- the average compressive strength of all 4420 tested concrete samples amounted to 47.0 MPa, standard deviation was 9.1 MPa, and variation index 0.194;
- the increase of density in the hardened state is generally followed by improvement of concrete's compressive strength;
- with application of special chemical admixtures and adequate execution of concrete works, at the same time respecting characteristic thermo-hygrometric conditions in Serbia, the term „construction season” is gradually loosing its traditional meaning; as it is shown in this paper, concreting can be performed practically during the whole year, almost without any problems.

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REZIME

STATISTIČKA ANALIZA REZULTATA ISPITIVANJA KVALITETA BETONA

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U radu je prikazana statistička analiza rezultata ispitivanja čvrstoće pri pritisku i zapreminske mase kontrolnih betonskih uzoraka dobijenih u Laboratoriji za materijale Građevinskog fakulteta Univerziteta u Beogradu, u toku 2012. godine. Ispitivanja su obavljena na ukupno 4.420 betonskih uzoraka, uzorkovanih na više lokacija - na mestu proizvodnje (u fabrikama betona) i na mestu ugradnje (na različitim gradilištima). Naime, reč je o uzorcima proizvedenim na petnaest betonskih baza, odnosno o uzorcima betona ugrađenih u 50 armiranobetonskih konstrukcija različite namene, koje je tokom 2012. godine izvodilo dvadeset dva različita izvođača. Poznata je činjenica da su ostvarene vrednosti čvrstoće pri pritisku betona veoma važne, kako za procenu kvaliteta i trajnosti betona u konstruktivnim elementima, tako i za proračun njihove granične nosivosti. Osim rezultata ispitivanja čvrstoće pri pritisku, analizirani su i podaci o zahtevanim (projektovanim) markama betona, o tome koliko se ostvarene marke poklapaju s projektovanim markama betona, zatim o dobijenim vrednostima zapreminskih masa, kao i o učestalosti izvođenja betonskih radova u toku predmetne - 2012. godine.

Ključne reči: čvrstoća pri pritisku, zapreminska masa, statistička analiza

SUMMARY

STATISTICAL ANALYSIS OF CONCRETE QUALITY TESTING RESULTS

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This paper statistically investigates the testing results of compressive strength and density of control concrete specimens tested in the Laboratory for materials, Faculty of Civil Engineering, University of Belgrade, during 2012. The total number of 4420 concrete specimens were tested, which were sampled on different locations – either on concrete production site (concrete plant), or concrete placement location (construction site). To be exact, these samples were made of concrete which was produced on 15 concrete plants, i.e. placed in at 50 different reinforced concrete structures, built during 2012 by 22 different contractors. It is a known fact that the achieved values of concrete compressive strength are very important, both for quality and durability assessment of concrete inside the structural elements, as well as for calculation of their load-bearing capacity limit. Together with the compressive strength testing results, the data concerning requested (designed) concrete class, matching between the designed and the achieved concrete quality, concrete density values and frequency of execution of concrete works during 2012 were analyzed.

Key words: compressive strength, density, statistical analysis